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LEARNING.

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A REPORT ON LEARNING PSYCHOLOGY AND ITS RELATIONSHIP TO THE STUDY OF SCHOOL LEARNING EMPHASIZES THE INCREASING INTERACTION BETWEEN THEORISTS AND EDUCATIONAL PRACTITIONERS, PARTICULARLY IN ATTEMPTING TO LEARN WHICH VARIABLES INFLUENCE THE INSTRUCTIONAL PROCESS AND TO FIND AN APPROPRIATE METHODOLOGY TO MEASURE AND EVALUATE LEARNING. "LEARNING PROCESSES" IS THE SUBJECT OF PART I OF THIS REPORT AND INCLUDES SUBHEADINGS (1) REINFORCEMENT AND EXTINCTION, (2) GENERALIZATION, (3) DISCRIMINATION, (4) ATTENTION, AND (5) PUNISHMENT. PART II, "CATEGORIES OF BEHAVIOR," INCLUDES (1) ROTE VERBAL LEARNING, (2) PSYCHOLINGUISTICS, (3) MEMORY, (4) CONCEPT LEARNING, (5) PROBLEM SOLVING AND THINKING, AND (6) PERCEPTUAL-MOTOR SKILL LEARNING. AN EXTENSIVE BIBLIOGRAPHY IS INCLUDED. THIS DOCUMENT IS A PREPRINT OF A CHAPTER TO APPEAR IN THE ENCYCLOPEDIA OF EDUCATIONAL RESEARCH, FOURTH EDITION, NEW YORK, MACMILLAN, 1969. (MS)

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Learning

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LEARNING

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Science and Application

The processes by which learning occurs are the subject of scientific investigation, and it is to be expected that the study of learning should provide knowledge that educators can use in designing instructional environments and in carrying out the educational process. However, scientific findings and theories rarely are immediately available for practical use, and translation and development are required for their possible application. The assumption, too often made in the past, that the findings and theories of learning could be presented directly to educators for their use is not viable. While the analysis of learning is becoming increasingly relevant to educational problems, more needs to be understood about the process between basic science, applied science, and development that leads to the methods and technology which can be used by the practicing educator. Five functions have been described as necessary for the successful relationship between research, development, and application, whether the outcome be a transistor or a new method of teaching arithmetic (Gilbert, 1965).

The first function, exploratory research, which the scientist calls theoretical, basic research, is characterized by questioning attitudes and relative independence of the application or further development of existing procedures or knowledge. In a coordinated research and development setting, the exploratory research operation, which serves as a channel in contact with significant developments in science, may be the determining factor in whether exploratory scientists work on problems relevant to practical innovation.

A second research function, fundamental development, is the investigation of the many variables relevant to principles discovered in exploratory investigations. In transistor development, much experimental work was required to understand the characteristics of the materials and conditions that had some bearing on the construction of a transistor. In psychological research relevant to education, exploratory work has been undertaken on methods for measuring human attending behavior. However, more needs to be known about the variables that influence this behavior. Since the child learning arithmetic must learn, at the outset, certain kinds of "looking" behavior when regarding a field of numerals, the investigation of attending behavior has important implications for the training of early habits involved in number and word perception. When this work of fundamental development is carried out, engineered methods of teaching arithmetic and reading must then still proceed.

The third function, specific development, relates to the fact that after the theory of the transistor and its variables were discovered, the transistor had yet to be produced. Producing an efficient transistor required skills rather different from those involved in the more "basic" laboratory. Parts had to be acquired, investigated, and assembled with an eye toward use in the field. The production of an actual working transistor serves as both a test of the value of the preceding research, and also feeds back problems to the basic laboratory. Similarly, once the variables involved in learning number concepts have been investigated, the specific development program has still to produce an arithmetic teaching program. The arithmetic teaching items must be written and revised on the basis of testing with small groups of children in the laboratory. When the program is actually taken into the classroom, the development people will continue to gather information and revise their material accordingly.

Design and proving is the fourth function. Once transistor or arithmetic programs are developed into functioning realities, they are not yet ready for introduction into field communication systems or into classrooms. The transistor developed in the laboratory may be one which would fail in the arctic cold, and the arithmetic program may fail with certain students. The product must undergo many detailed modifications before it can be a usable instrument in the school. Efficient and inexpensive machinery and procedures for its use must be designed; and changes in the work habits of the teacher and in the structure of the classroom may be required. Design and proving engineers are also charged with demonstrating product effectiveness under field conditions. What is important here is to test out the efficiency and economic value of variations in the conditions of use.

Finally, having researched and developed a new product, the R & D organization cannot detach itself from further implications, and a fifth function, training and follow-through, is required. It is necessary to pass on the knowledge by providing a training program for certain key people in the schools. Furthermore, channels must be kept open for feedback about new problems or developments with the product or procedure.

The above components seem to be necessary parts of the structure required for getting knowledge from the science of learning into practical educational efforts even though the regularity of the order of these components may be overemphasized. This review reports on basic research in learning, essentially representing the first two components just described.

The Psychology of Learning and the Design of Instruction

The employment of a psychological basis for the design of instructional procedures and materials suggests the following general requirements for this kind of development: (a) specification of the properties of the behavior or task to be learned; (b) specification of the characteristics of the learner; (c) specification of the conditions which permit the individual with the behavior specified in (b) to attain the behavior described in (a); and (d) specification of the conditions under which the learned behavior will be maintained and the individual will be motivated to use it (Glaser, 1965, 1966).

Analysis and classification of the behavior to be learned. This is an increasingly prominent feature in the psychology of learning and in attempts to apply it (Melton, 1964; Gagné, 1965b; Glaser, 1962; Bruner, 1964; Miller, 1965). Two points are to be made in this regard.

The first is that the older, all-inclusive theories and schools are gone as major psychological forces and are replaced by more miniature systems which have resulted from the application of certain methods of behavioral analysis or of certain explanatory concepts and processes to describe a class of behavior. The working assumption at the present stage of learning theory is that the various classes of behaviors that human beings display differ in their stimulus and response characteristics and in the ways in which stimulus and response are related or structured. Depending upon these properties, the conditions for the learning of different categories of behavior have similarities and differences (Gagné, 1965a; Mechner, 1965, 1967). This fact has important consequences for the analysis of learning tasks relevant to classroom subject matters. School learning must be analyzed not only in terms of its knowledge content, e.g., vocabulary, grammatical structure, and scientific laws, but also in terms of the kind of behavioral repertoire that is being learned, e.g., a verbal association, discrimination learning, a behavioral chain, concept formation, etc. Categorizing learning tasks in this way permits specific investigation of the relevance of the variables that influence them and the design of effective conditions for the learning of these classes of behavior.

The second point is that the extrapolation of psychological findings to school learning requires that the scientific study of learning address itself to behavior at a level of complexity useful for describing educational problems. Until recently, psychology has been deeply involved in the analysis of simplified behaviors and processes (Hilgard and Bower, 1966). There are now apparently some trends toward synthesizing and reexamining the components of behavior studied in the laboratory as they are relevant to "real" behavioral complexity. This trend toward synthesis has been encouraged by the increasing movement of individuals between laboratory study and educational problems, as was done by Thorndike and more recently by Skinner. In the laboratory, a behavioral task performed by a subject has special properties for particular scientific interests; the task involved is so designed that its properties are clear enough for experimental investigation. In contrast, the behavior presented by school learning is not designed for the laboratory, and needs to be analyzed so that it can be subjected to study. The necessity for this kind of "task analysis" adds a new requirement to the study of learning. Tasks cannot always be selected arbitrarily as they can be for laboratory study, but tasks appropriate to school learning must be analyzed into the kind of taxonomy and behavioral categories which learning theory is able to provide.

Specification of the characteristics of the learner. This raises the general problem of the interaction between individual differences and learning method. It is now well recognized that the fact of individual differences has been more honored in the breach than in the observance in educational procedures. In the study of learning, there has been increasing concern about the lack of contact between test-and-measurement psychologists studying individual differences and the experimental psychologists studying learning (Cronbach, 1957; Gagné, 1967; Glaser, 1967). The investigation of individual differences in the study of learning and the incorporation of individual difference parameters in learning theory is an unavoidable assignment for increasing relevance to instructional practice.

Specification of the conditions for learning. Once the nature of the task to be learned and the entering characteristics of the learner are described, the conditions under which learning will occur can be specified. Instruction and the educational process is defined as providing the environmental conditions which allow the learner to proceed from a present "entering" behavioral repertoire to the educational goals described as the desired outcomes of instruction. Much of current psychological thinking (Underwood and Schulz, 1960; Skinner, 1957) divides learning into two aspects: (a) response learning by which new forms of behavior are established--which refers to the fact that a significant component of learning is an increasing precision of the student's responses, and that both learning experiments and classroom instruction set particular criteria for acceptable learner responses; (b) environmental or stimulus control by which learned responses are associated with or come under the guidance of certain stimulus contexts; effective learning is characterized by well executed performance taking place in an appropriate situation. A wide variety of behaviors, from rote learning to problem solving, involve competent performance (that is, responses performed according to certain criteria defined as competence) which occurs in discriminated stimulus contexts. Awkward and imprecise responses and responses which are inappropriate to a particular situation are descriptive of poor performance and ineffective learning. Effective conditions for learning lead to response acquisition and the stimulus or context control of these responses. In addition, an adequately learned performance is characterized not only by the facility with which it occurs in different contexts but also in terms of its long-range properties, e.g., how well it is remembered, the degree to which it transfers to and facilitates new learning, the extent to which it continues to be engaged in for relatively long periods of time, and the extent to which it becomes increasingly independent from the supports required in earlier stages of competence. These long-term properties of learning are especially characteristic of school learning, and their investigation is a significant aspect of the scientific study of learning relevant to instruction.

It has been indicated that the fundamental processes of learning dictate the nature of the conditions for learning which must be implemented in educational design. The degree of relevance of these processes to how learning occurs is, to a large extent, a function of the kind of behavior involved. From this point of view, this review is presented in two main parts: learning processes and categories of behavior. In the ensuing paragraphs there is some sensitivity to the growing relationship between how behavior is learned and how it is taught.

Part I: Learning Processes

The learner acts upon his instructional environment, changes it, and is changed in turn by the consequences of his actions. Certain processes alter behavior so that it achieves a useful interchange with a particular environment. When appropriate behavior has been learned, it sets up new consequences in the environment which work through similar processes to maintain this behavior and use it to develop more competent and subtle behavior. Relevant questions for a science of learning are: How is the behavior of the learner influenced and shaped by the environment or the people in it? How does the learner come to control his environment; and how, in turn, does this environment influence him? By arranging environmental consequences or contingencies, the probability with which behavior occurs can be increased; by eliminating the consequences, the probability can be decreased. These are the processes of acquisition and extinction. The particular properties of the behavior acquired depend upon the details of the environmental contingencies. A complex repertoire can be taught by a series of environmental changes, each stage of which allows the learner to respond and also prepares him to respond at a later, more complex stage. Such an instructional sequence is carried out when the teacher devises environmental changes as the student goes through a curriculum; the instructional sequence also might be prescribed in advance as in certain kinds of programmed instruction and other lesson materials. Certain behaviors require extensive instructional sequences; others as a function of past learning are acquired rapidly through such environmental events and procedures as verbal instruction and observation.

As responses and the integration of responses are learned, they are acquired in relation to particular events or stimuli so that the behavior performed occurs relevant to some context. Behavior is learned in the presence of contextual stimuli and is therefore likely to occur in the presence of this context. In a sense, stimuli come to control certain kinds of behavior so that, for example, competence in a subject matter is displayed when in the presence of certain subject-matter stimuli the student responds with appropriately skillful behavior. The more readily a stimulus context sets the occasion for the occurrence of certain behavior, the greater the degree to which it can be said that the situation exerts stimulus control over the behavior. "Control" may be too awkward and dictatorial a word to use in the educational enterprise, but when one thinks of school learning, it is not too difficult to accept the statement that a competent performer is to some extent controlled by the rules and discipline of the subject matter. As competence grows, the student masters these controlling relationships and proceeds to manipulate them in creative ways. The topic of stimulus control is an old one in the psychology of learning and generally refers to the fact that an antecedent stimulus determines the probability of learned behavior. Work in classical and respondent conditioning is concerned with the establishment and strengthening of stimulus-response relationships. Classical conditioning has dealt primarily with reflex-type responses where an already strong response is brought under the control of some stimulus which did not originally evoke it. A transfer of stimulus control occurs from the original unconditioned stimulus to the new or conditioned stimulus (Grant, 1964). In instrumental or operant conditioning, the distinction between response learning and bringing the response under the control of an appropriate stimulus context can be seen clearly. In the classical experiments of Thorndike's cats in a puzzle box and Skinner's lever-pressing situations, the subject's behavior is influenced as a result of a response being made and followed by a consequent environmental change, e.g., reinforcement or punishment. Concurrently, this response is differentially reinforced so that it occurs in the presence of particular stimuli. Stimulus control can be established with respect to a response that is available and well-learned, or with respect to behavior that is in the process of being learned (Terrace, 1966).

Two major phenomena in stimulus control are generalization and discrimination. These are processes describing the characteristics of a response as it becomes related to a stimulus. Generalization refers to the well documented (Kimble, 1961, chap. 11) characteristic of behavior that when an individual learns to behave in a certain way in the presence of a particular stimulus, this behavior also occurs in the presence of stimuli having common properties with the stimulus or stimulus class used during original learning. Discrimination learning is the name for the process by which stimuli come to acquire selective control over behavior. A learner is said to have learned to discriminate when he has learned to respond differentially in the presence of two stimuli and does this reliably. Basic to generalization and discrimination are the processes of reinforcement and extinction which refer to the ways in which behavior is strengthened and diminished.

Reinforcement and Extinction

The law of reinforcement indicates how behavior can be shaped and learned through the use of reinforcers. A reinforcer is defined as an event, stimulus, or state of affairs which changes subsequent behavior when it follows the behavior in time. An event is identified as a positive reinforcer when its presentation, following (contingent upon) the occurrence of a response, increases the probability of occurrence of that class of responses. Responses are also strengthened by negative reinforcers; these consist of noxious or aversive events which are removed if the response occurs. Although there are various theoretical interpretations about the acquisition of behavior through reinforcement, in terms of drive reduction, the law of effect, and contiguity, the operations employed to manipulate responses in the course of learning are similar for the different types of explanatory theories. The operational statement is that behavior is acquired as a result of a contingent relationship between the response of an organism and a consequent event. There seems to be little doubt that a significant aspect of educational and instructional practice is the management of reinforcing operations. The term reinforcement is usually applied when an event (1) is response contingent, (2) produces some relatively permanent behavioral changes (learning), and (3) is related to some relevant motivational state of the learner, e.g., conditions of deprivation and past training. Generally, the major classes of events which can produce reinforcing effects are categorized as: (a) primary positive reinforcement--the presentation of events such as food, water, sexual contact, which are related to some organic need state; (b) primary negative reinforcement--the removal of aversive stimulation such as electric shock, intense light, or loud sound; (c) secondary positive reinforcement--the presentation of a stimulus which has had prior association in the history of the learner with the condition in category (a) (these latter are conceived to be learned reinforcers like money, praise, social approval, attention, dominance, etc.); and (d) secondary negative reinforcement--the removal of a stimulus which has had prior association with the events in category (b) (Kimble, 1961; Wike, 1966).

Sensory reinforcement. A recent, increasingly active area of study has demonstrated behavioral effects resulting from the response contingent presentation of stimuli which do not fall under these four categories but which conform to the three criteria for reinforcement presented above (Kish, 1966). This new category, referred to as sensory reinforcement, seems quite relevant to educational matters. Sensory reinforcement appears to be a primary reinforcement process resulting from the presentation or removal of stimuli of moderate intensity. The phenomenon is observed in experiments with animals and children where visual stimulation, such as the onset of a light contingent upon a response, is found to act as a reinforcer; also, visual and auditory exploration contingent upon a response results in learning (Kish, 1966). In an analogous way, it is suggested that the manipulatory behavior in a puzzle problem is reinforced by the visual, auditory, kinesthetic, and tactile consequences of the manipulative behavior itself (Harlow, 1950; Harlow and others, 1956). It appears that stimulus change in many modalities may function in a reinforcing capacity. Apparently, reinforcing forms of stimulation events may be found in many sensory modalities, and a basic problem in understanding the process of sensory reinforcement is specification of the properties of the reinforcing stimuli which distinguish these events from stimulation which is not reinforcing. It has been proposed that such reinforcing stimuli can be characterized as novel, complex, incongruous, etc., and as arousing or relieving of uncertainty or conflict (Berlyne, 1960). Experiments indicate that decreased novelty is associated with diminished reinforcement potential (satiation), and that non-exposure to the reinforcer may permit recovery of its reinforcing potential. Hence, the reinforcing effects of a novel stimulus can be manipulated by prior exposure of the subjects to similar or dissimilar stimuli. In general, the reinforcing properties of the stimulus are influenced by previous contact with it. Students subjected to different lengths of information deprivation show behavior positively related to the length of the deprivation period and to the amount of information in the reinforcing stimulus (Jones, 1961; Jones and others, 1961). Complexity is related to novelty in the sense that the more complex the stimulus, the longer it takes for a stimulus pattern to become familiar and to satiate. The complexity of a stimulus pattern is related to its attention-holding value, its exploratory-arousing value, and its sensory-reinforcing value; and the variables that contribute to the complexity of stimuli are a matter for study (Berlyne, 1960).

Exploratory behavior and curiosity. The properites of stimuli that act as sensory reinforcers also tend to elicit exploratory behavior and curiosity. Prior to 1950, research on this kind of behavior was absent except for a few isolated instances; in the past decade there has been increased interest (Fowler, 1965; Berlyne, 1960). Research has been aimed at the discovery and identification of variables which serve to elicit and maintain curiosity and exploratory behavior in the absence of conventional laboratory motives such as hunger or thirst or other conditions of deprivation. The specific responses which have been observed are such behaviors as orienting, approaching, investigating, and manipulating. Research has indicated that the strength of exploratory behavior which is elicited is positively related, within limits, to the degree of change in the stimulus situation provided by the novel, unfamiliar, or incongruous situations introduced into the environment. Too great or too abrupt a change, however, is disrupting and may preclude exploration. In complex situations, an individual encounters change by way of his interaction with or manipulation of the elements involved. Such interaction provides the stimulus change which can elicit curiosity and exploratory behavior.

Investigations also have demonstrated that behaviors are learned that lead to a change in the stimulus display. Thus, in addition to stimulus change eliciting exploratory behavior, experiments show that organisms will respond in order to secure novel, unfamiliar stimuli. In general, these findings demonstrate that stimulus change or sensory variation may be employed selectively to reinforce behaviors which result in stimulus change and that this variation in the stimulus situation will serve concomitantly to elicit exploratory behavior. When stimulus change is used as a reinforcing stimulus, it seems reasonable to hypothesize that learning variables which influence acquisition and extinction of other learned behavior will influence the acquisition and extinction of exploratory and curiosity behavior. This suggests that a student's curiosity and explorations may be both elicited and selectively maintained in an instructional environment which provides for appropriate variation and change in both the stimulus characteristics of the subject materials confronting the student and also the responses required of him by these materials.

The relativity of reinforcement. The general conjecture for the kinds of reinforcing events that have been generally studied in the past and for the more recently investigated sensory reinforcements is that these kinds of stimuli act as reinforcers which have some drive reduction function. A somewhat different approach to the notion of reinforcement has been introduced (Premack, 1959; 1965). Reinforcement has been formulated in terms of the preference values of certain activities or the probability of occurrence of these activities in a person's repertoire. A more highly preferred activity can be used to reinforce a less preferred activity. An activity will only reinforce activities of lower preference value or of lower probability of occurrence. Common sense examples of this phenomenon are that parents permit watching television only after eating dinner or permit eating dessert only after proper food has been eaten. This kind of hierarchical or relativistic nature of reinforcement has been demonstrated in a variety of experiments. The relative value of two events can be changed by altering relevant conditions in an individual's history. Thus the relative preference for eating versus sleeping can be manipulated by food or sleep deprivation respectively. This relativistic notion of reinforcement points out that of any two responses, the one that occurs most often when both are available can reinforce the one that occurs less often. For example, if for a child, playing is a higher strength behavior than eating, playing might be used as a reinforcing event for eating behavior; or if certain words occur with a higher probability than others, they might be used as reinforcing stimuli for words that have a lower probability of occurrence. Implicit in this kind of analysis of reinforcing events is that the particular event that constitutes a reinforcement is not necessarily a stimulus situation external to the learner so much as it is the behavior produced by the situation--under certain conditions it may not be the food but the eating that reinforces a hungry person. The reinforcing event may not be so much the achievement of the goal but the behavior produced by attaining the goal. Thus, reinforcers may be defined in terms of either external stimuli or in terms of behavior (which produce some sort of internal stimuli). Either definition may serve a particular purpose and both seem to be useful ways of thinking about the operation of reinforcement.

Behavior sequences. If carrying out a learned behavior can be reinforcing, then in a chain of activities which terminates in a reinforcing event, each response can act as a reinforcer to a previous response if it has a higher probability of occurrence than the behavior it is reinforcing. The learning and maintenance of long, orderly sequences of behavior has been of interest to psychologists for a long time (Kelleher, 1966). Human behavior provides many examples--throwing a ball, playing the piano, solving a geometric proof, memorizing a poem, driving a car. Early interests in this problem of behavioral sequences is exemplified by the classical double alternation problem where a rat in a maze learns that two right turns are followed by two left turns (Hunter, 1920). Double alternation lever pressing has also been studied (Schlosberg and Katz, 1943). In these situations the experimenters were impressed with the fact that the behavior sequence becomes condensed in time and content, and stimuli and responses are fused into a continuous behavior pattern which is performed with relative ease. Such increasing precision and ease is characteristic of much of human behavior where a laborious sequence is eventually performed rapidly and smoothly, and intervening members of the chain apparently are dropped out or become covert. A prevalent hypothesis in the development of chains (Keller and Schoenfeld, 1950, chap. 7) is that in a behavioral sequence the stimulus first becomes a discriminative stimulus for some response; once so discriminated, it can become a reinforcing stimulus. In the chain, a response produces a stimulus, either exteroceptive or proprioceptive, and this stimulus serves as a reinforcer for the previous response and the discriminative stimulus for the next response. Response-produced stimuli are hypothesized to be an essential aspect of behavioral chains, and this notion has generated interesting research activity.

The above notions of chaining have been extrapolated to instructional processes (Gilbert, 1962; Gagné, 1965a, chap. 4; Mechner, 1965, 1967). This extention represents an especially interesting way in which laboratory studies might influence instructional research. Once the members of a chain of behavior have been identified, an instructional sequence to teach the chain might proceed, with appropriate practice, as follows: in a chain consisting of four members, a - b - c - d, the first response the student should learn is the last one in the chain, response d. Therefore, the first teaching step would be given a - b - c, carry out d, and the correct response is d. Next the student should learn to carry out the last two members of the chain; the teaching step would be given a - b, complete the sequence and the correct response would be c - d. Next given a, perform b - c - d. Finally, the student would carry out the complete chain unassisted. This suggestion implies that operation d is learned first, then c - d, since d as a higher probability behavior can reinforce the new response c and so on with operations a - b - c - d. The student always carries out the chain in a forward direction and does not perform the behavior backwards. What occurs backwards is the way in which the elements of the chain are added to the student's repertoire. Practical examples that have been suggested are: When teaching a child a manual skill, such as tying his shoelace, start by presenting him with the bow almost completely tied, but only loosely so, and allow him to tighten it. When he can do that, present him with the bow almost complete and allow him to complete it and make it tight. This procedure is continued, allowing the child to complete longer and longer segments of the chain until he can start with untied laces. When learning a proof in geometry, start by studying the proposition to be proved. Then look at the step in the proof which just precedes the final proposition and understand the final step. Next move to the preceding step, and so forth until the starting axioms have been reached. In general, the procedure is reminiscent of the advice to start solving a problem by asking what the problem would look like when it is solved and then proceed to examine the kind of situations that lead up to the state of affairs defined as solution or terminal performance.

Reinforcement schedules. Most often in practical affairs, reinforcing events follow behavior on an intermittent basis; it is the exception rather than the rule that an individual is regularly and continuously reinforced each time a behavior is performed. It has been shown that the schedule on which reinforcement occurs strongly influences behavior and is often much more important than the nature and quantity of the reinforcer. Schedules of reinforcement represent one of the most intensively studied influences on the generation and maintenance of operant behavior (Morse, 1966). A very wide range of behaviors has been produced in lower organisms by different schedules involving intricate relationships between responses and their contingent reinforcements. Schedules of reinforcement seem powerful enough in producing patterns of responding that many investigators consider them a pervading influence in the psychology of learning (Skinner, 1966). In laboratory studies, a schedule of reinforcement is a prescription for initiating and terminating discriminative and reinforcing stimuli in time and in relation to some behavior. Schedules have been classified (Skinner, 1938; Ferster and Skinner, 1957) in terms of those that reinforce a response on the basis of time (interval schedules) and on the basis of response occurrence (ratio schedules). Interval schedules consider the time that has elapsed since some event, either a response or a reinforcement; ratio schedules make reinforcement contingent upon the number of emitted responses. Complex schedules are built up as variations or combinations of ratio and interval schedules. A notational and terminological system has been developed to systematically describe the different kinds of reinforcement schedules (Ferster and Skinner, 1957). When learning occurs under two different schedules, the differential effects are quite apparent. In animals under one condition of reinforcement (fixed-ratio reinforcement), the response being reinforced takes place to the exclusion of all other behavior, and the animal works at a great rate and seems "highly motivated, persistent, and industrious." However, if another schedule is in effect (a variable-interval schedule with a low-rate contingency of reinforcement), responses occur at a much lower rate and there are periods of "apparent disinterest" in making a response. In general, the work on schedules in lower organisms has represented an active search on the relationship between the learning of complex patterns of behavior and the selective and strengthening effects of reinforcement.

Related to the notion of schedules of reinforcements is the long-standing evidence that delay of reinforcement influences learning (Hull, 1943, chap. 10; Spence, 1956, chap. 5). In general, responses temporally near reinforcement are learned more quickly than responses remote from reinforcement (Kimble, 1961, chap. 6). The shorter the delay of reinforcement the steeper the slope of the learning curve. Much of the attention to programmed instruction and teaching machines is centered around the necessity for decreasing the delay of reinforcement in the instructional process. Nevertheless, the effect of reinforcement delay is far from clear cut. It is apparent that individuals can learn to tolerate such delay and can learn to fill in delay intervals with symbolic reinforcers and verbal mechanisms (Deese and Hulse, 1967, chap. 2). A significant aspect of delay is that during the delay period other behaviors intervene which may be unrelated or detrimental to the ongoing learning. Such irrelevant behavior, if it is allowed to occur, may be strengthened by the onset of the reinforcer, and in this way such behaviors as inattention and distraction might be learned and maintained. The behavior that intervenes may be behavior which has been previously learned and, hence, is stronger than the newly learned behavior and requires less reinforcement for its acquisition.

In the light of the above relationships of reinforcing conditions and operations to such behavior as curiosity, exploration, persistence, inattention, and the like, there is a general growing doubt that the process of reinforcement can be legitimately separated, as it has been in the past, from the concept of motivation. Much of the literature that can be placed under the heading of reinforcement might also be classified under the heading of motivation. Indeed, the two are closely connected and may eventually become indistinguishable.

Extinction. The primary effect of reinforcement is to strengthen behavior. Once the behavior is acquired and reinforcement is terminated, the behavior persists for a while, becomes weaker, and gradually declines in frequency. Extinction refers to this subsequent decline after reinforcement has been discontinued. Relatively speaking, the acquisition of behavior occurs rapidly and extinction is slow. It has also been observed that when reinforcement is discontinued, behavior during extinction is intensified before it subsequently declines (Amsel, 1958, 1962; Morse, 1966). A frequently reported phenomenon about extinction is that there is increased resistance to extinction as a result of partial reinforcement during acquisition, as compared with continuous reinforcement. More generally it has been pointed out that when learning occurs under relatively unfavorable conditions such as a response requiring much effort, punishment at the goal, delayed reward, or frequent extinction trials, a greater resistance to extinction is manifested (Festinger, 1961; Lawrence and Festinger, 1962).

The above facts about extinction and the general observation that learned responses show little or no tendency to be forgotten with the mere passage of time lead to the notion that extinction is the result of some active process associated with nonreinforcement. This has led to theory and experimentation to explain the nature of extinction; in general, many of the investigations carried out have been designed to support or refute theoretical explanations of the extinction process. The hypotheses that have been advanced to explain extinction employ a wide variety of concepts--inhibition, response competition, discrimination, frustration and punishment, cognitive dissonance, and generalization decrement (Kimble, 1961, chap. 10). While certain facts about extinction may be evident, the variables controlling extinction may be evident, the variables controlling extinction seem even more complex than those controlling acquisition.

Generalization

When a learner has acquired a response to a particular stimulus it is evident that other "similar" stimuli will also elicit the response that has been learned; once a response has been reinforced in one situation, the probability that the response will occur in other similar situations is increased. The phenomenon that occurs when a stimulus situation, different from the one in which the learner has been trained, sets the occasion for the occurrence of the learned response is known as stimulus generalization. There is also a comparable phenomenon less well studied, known as response generalization or response induction. Early in its development, the concept of stimulus generalization was associated with neural mechanisms (Pavlov, 1927). The departure from this tradition is associated with Hull, Spence, and Skinner who conceived of it as an empirical behavioral phenomenon and deemphasized neural postulates. Generally speaking, generalization refers to making the same kinds of responses to different stimuli; as such, it involves learning common elements and disregarding differences, so that responses are made to new situations which are in some way similar to the situations in which previous learning occurred. Whether or not generalization is desirable or undesirable, appropriate or inappropriate, depends upon the particular task being taught.

The process of stimulus generalization has been widely studied and has been demonstrated in many species and in various learning situations to be a process characteristic of individual organisms (Guttman and Kalish, 1956; Kimble, 1961). The amount of stimulus generalization decreases with increasing differences between the originally learned stimulus and the newly presented stimuli; when response strength is plotted as a function of this difference, the result is a monotonic decreasing gradient between the original learning stimulus and the new stimuli. The process of generalization is influenced by a number of variables. The extent of a generalization gradient increases with the strength of the originally learned response so that the amount of stimulus generalization is increased as a response increases in strength. If a response is undergoing extinction, the range of generalization is restricted unless the original learning was under conditions of intermittent reinforcement. Increased motivation during learning increases the range of generalization. Intermittent reinforcement results in wider generalization than continuous reinforcement. The intensity of stimuli influences generalization; new stimuli, stronger in intensity than the original stimulus, will increase the amount of generalization. The conditions of original learning influence generalization so that if the subject learns to discriminate stimuli along the dimension of generalization, the generalization gradient is steeper. Currently, active research is being carried out on the process of generalization (Mostofsky, 1965).

Since stimulus generalization occurs along a dimension of stimulus similarity, the question arises as to the perception and properties of "similarity." Generalization occurs along many kinds of continua. Studies of "semantic generalization" show generalization gradients with respect to meaning and language habits and indicate that generalization occurs along dimensions of similar words and between a word and its object. Similarity along such dimensions is frequently explained in terms of mediation, i.e., the extent to which different stimuli elicit the same or similar mediated responses. The measurement of similarity is a problem requiring the development of quantitative measures. It has been pointed out (Shepard, 1965; Cross, 1965) that for the purpose of constructing gradients of generalization there does not appear to be any one measure of the similarity or dissimilarity between stimuli that has the kind of fundamental status that number of trials or number of reinforcements has for the construction of curves of acquisition. A problem under study is the determination of behavioral measures that can be used for a quantitative scaling procedure which specifies the underlying dimension of generalization.

Stimuli have various functions. They set the occasion for a response as elicitors or discriminative stimuli; they serve as reinforcers; and they also serve as inhibitors. Generalization effects refer to a variety of stimulus properties, although the properties have been less well studied in cases other than where stimuli serve as elicitors or discriminative stimuli. Generalization can occur with respect to a response which is inhibited in the presence of a stimulus, and gradients of inhibition have been empirically shown to exercise a range of inhibitory control (Jenkins and Harrison, 1962). Exposure to a punishing event which is consistently preceded by a neutral stimulus endows that stimulus with a capacity to inhibit or suppress behavior, and generalization occurs to stimuli which are similar to it so that these stimuli also exhibit this capacity (Estes and Skinner, 1941;

Hoffman, 1965). Generalization gradients have also been studied for avoidance behavior, and there is the suggestion that avoidance resulting from punishing stimuli can generalize very broadly; extremes of such kinds of stimulus generalization are found in neurotic and psychotic individuals (Hearst, 1965). Stimuli are not all equally effective in controlling behavior and there might be postulated some kind of underlying attending hierarchy so that certain cues in a stimulus situation, e.g., color, size, form, may be more effective in facilitating generalization or discrimination (Baron, 1965).

Discrimination

In a manner analogous to the contrast between acquisition and extinction, so generalization and discrimination can be compared. Discrimination learning is a process by which stimuli come to acquire selective control over behavior; particular situations set the occasion for the occurrence of behavior in that situation. A learner is said to have learned to discriminate between stimuli when he responds differentially in different stimulus situations and does so reliably. In a simple two-choice discrimination problem, the subject learns to make a response in one way if an instance of stimulus A occurs and to choose another response if stimulus B occurs. The simplest type of discrimination problem frequently used in the laboratory as a reference experiment for theoretical interpretation is where the learner is reinforced for responding in the presence of one stimulus, the S+, and not reinforced for responding in the presence of another stimulus, the S-. Traditionally, in such discrimination learning problems both stimuli are presented to the learner, he initially responds to both, and eventually develops differential responses to each. The classical explanation of this kind of situation describes the learning that takes place in terms of reinforcement, extinction, and generalization (Spence, 1936; Hull, 1950; Keller and Schoenfeld, 1950). A response is acquired to the S+ through the cumulative effects of reinforcement. Extinction (or conditioned inhibition) occurs to the S-. The responses made to the S+ receive an increment in response strength, and depending upon the similarity of the stimuli, there is generalization to the S- which receives a weaker increment in response strength. In a similar fashion, extinction or inhibition to S- generalizes to the S+. As this process is repeated, in conjunction with repetition with the S+ and S-, the strength of responding to the two discriminative stimuli draws apart and a discrimination is established. The net tendency to respond to any stimulus is then given by the interaction of the generalization of acquisition and the generalization of extinction. This formulation of the process of discrimination learning has provided the basis for many experiments and theoretical formulations.

One of the implications of the assumption of stimulus generalization in theories of discrimination learning is that responding in the presence of one stimulus is related to responding in the presence of another stimulus. In an experimental situation where reinforcement or extinction is manipulated for one stimulus and held constant for the other, the expectation is that responding to the fixed stimulus should increase or decrease as a function of the generalization between the two stimuli. In certain discrimination situations, however, an opposite result has been observed where response rates are negatively correlated; a reduction in reinforcement in one stimulus is accompanied by an increase in responding to the other stimulus. This effect has been called "behavioral contrast" and has been observed with animal subjects (Reynolds, 1961). This has generated some examination of the classical notions of discrimination learning.

Recently, to some extent growing out of work on teaching machines, a new procedure for discrimination learning has been investigated which has led to a new view of the process. An expressed principle in programmed instruction is that an optimal arrangement of a programmed sequence is one in which the student makes few or no errors in the course of learning. With this in mind, recent research has been carried out in which a discrimination is taught by a procedure in which the learner never responds or makes minimal responses to the S- throughout learning (Terrace, 1963). The procedure used to teach a discrimination is based on procedures previously shown to be effective in minimizing the occurrence of errors (Skinner, 1938; Schlosberg and Solomon, 1943); the critical variable in these early studies appeared to be the time and manner of the introduction of the S-. The procedure recently used involves introducing the S+ in its final form, but introducing the S- gradually (initially, for very brief durations and at very low intensities); over successive trials the intensity and duration of S- are gradually increased to their full value. In this way, a discrimination can be taught with minimal occurrence of "errors," i.e., nonreinforced responses to S-. This procedure was originally carried out in the animal laboratory where it was compared to the classical discrimination learning procedure. This comparison suggests that discrimination performance as a result of training by the errorless method was superior in two senses: (a) that there were no responses to the incorrect S- stimulus; and (b) that aversive or "emotional" behavior was not built up as a result of extinction to the S- stimulus. This study has been extended to the teaching of discriminations in young children and retardates (Moore and Goldiamond, 1964; Sidman and Stoddard, 1967).

Of special interest in discrimination learning is the question of what is the effective stimulus controlling the learner's performance. Generally, the effective stimulus that controls discriminative performance is a stimulus attribute or set of attributes present in the S+ and absent or different in the S-. The stimulus attributes become relevant because they correlate with the presence or absence of reinforcement. Relevant attributes can be complex aspects of a situation, including such relational features as larger than, different from, etc. This kind of relational discrimination learning has been studied in "transposition" experiments which have a long history in psychology (Kohler, 1918; Spence, 1937; Zeiler, 1963). Complex discrimination learning has been studied in a variety of interesting ways: (a) The ability to transfer and reverse a learned discrimination along certain dimensions has been shown to be related to developmental stages in children and seems related to their increasing proficiency in verbalizing the discriminative features involved (Kendler and Kendler, 1962). (b) The facility to become increasingly proficient in learning to learn discriminations over a series of tasks has been studied in the work on learning sets (Harlow, 1949, 1959). (c) The way in which a previously learned discrimination can facilitate learning in a new situation has been examined in studies on the acquired distinctiveness of cues (Lawrence, 1949, 1950).

Attention

Related to the control of behavior by selected aspects of a stimulus is the phenomenon of attention. The extent to which certain stimulus aspects of the situation fail to control or direct the learner's responses is often referred to as a failure of attention. Behavior labeled as attention has generally been conceived in terms of certain mediating responses that must occur before a stimulus element will reliably be associated with a response; such responses are considered preparatory responses which orient the learner to observe critical stimuli in a situation. These orienting responses (or receptor-exposure acts) are learned responses and as such are reinforced and extinguished (Spense, 1937, 1956; Skinner, 1953).

A response which causes an individual to pay attention to a particular attribute of a stimulus situation has been referred to as an observing response. These observing responses are reinforced because they produce or clarify a discriminative stimulus which then comes to control a response which is in its turn reinforced (Holland, 1958; Wyckoff, 1952; Atkinson, 1961). The observing response as it has been studied is primarily an overt act which produces, in some way, the stimulus involved in the ongoing learning. It also has been shown that learning can produce biases toward the use of a particular stimulus attribute (Berlyne, 1960). Previous reinforcement with respect to a particular stimulus element in one situation will transfer to other situations, and the learner's history can serve to make that aspect of the situation predominant or preferred as a cue for learning. When this learned cue is relevant, it can facilitate learning and where it is irrelevant, it can inhibit learning.

Attention has been considered in terms of a coding response where coding refers to a procedure for labeling and representing objects so as to provide a means for describing a complex stimulus by one or more of its properties (Lawrence, 1963). The "stimulus-as-coded" labels a particular stimulus as "blue," for example, which in turn serves to describe the stimulus as an entity to be responded to. If, in the course of learning, a stimulus pattern varies on many attributes, then during learning, different responses are tried out until the relevant attribute is settled on, and the subject learns to attend to that aspect of the stimulus as being relevant in this situation. In a variety of learning tasks, this sort of attribute learning (or learning what the functional stimulus is) occurs before learning, involving stimulus control over the response, takes place.

Attention has taken a key role in certain studies of discrimination learning with retardates, and in comparing the nature of discrimination learning between brighter and duller individuals (Zeaman and House, 1963). In an elaboration of the observing response model, two responses are postulated: one, an attention response to the relevant stimulus dimension, and two, the correct response to the positive cue of the relevant dimension. Experiments show that the differences between the brighter and duller subjects are not in the slopes of their learning curves but in the length of the initial plateau. This implies that it is not the rate of learning that distinguishes bright and dull, but how long it takes the attentional response to discriminate out the relevant stimulus cue; after this occurs, improvement is uniformly fast for both groups. The general postulation is that there are two aspects of learning involved: one aspect controlling any individual differences in the rate of acquisition and extinction, and the other controlling individual differences in the probabilities of paying attention to stimulus dimensions. A difficult discrimination task would be one in which the relevant dimensions involved have a low probability of being attended to; in an easy task, both bright and dull subjects have a high probability of paying attention. Retardate learners can be slow learners in the attentional phase, but once this occurs, they might learn in one or two trials. The initial probability of selecting a coding response, or discriminating out the positive stimulus, determines several aspects of discrimination learning: the length of the plateau prior to associative learning, the difficulty of the problem, and the "learning speed" of the subject.

A significant question in the study of attention is what variables influence stimulus selection during learning (Berlyne, 1960). The factors which determine initial attending hierarchies seem to be: (a) innate factors, which are, perhaps, interspecies differences in the saliency or importance of particular stimulus properties; (b) stimulus aspects, which emphasize a particular cue or give a feature a distinctive tag, e.g., intensity, vividness, size--these latter aspects are culturally learned or are features of the situation which arouse and reinforce exploratory and orienting behavior; and (c) specific past learning, in terms of training to look for certain attributes or variations in the situation. In this regard it is also likely that facility in performing attention behavior involving the discovery of new features in a situation can be reinforced by supplying the learner with relevant coding operations. In general, as more knowledge is obtained about attending behavior and discrimination learning, it seems that there may be some success in extending the discriminative capacities of individuals. As this occurs, the ability to make fine discriminations in tones, for example, may be less accepted as innate musical talent and more of a behavior that can be taught.

Some investigation has been conducted on the kind of learning that takes place when a learner observes someone else performing a response and attempts to imitate it. The variables that influence this kind of learning have been described (Bandura, 1962, 1965), but more experiments are needed to analyze the mechanisms by which this kind of behavior takes place. A program of research has been carried out in an attempt to understand how humans learn from written material (Rothkopf, 1965). The activities that are involved in this behavior have been referred to as attention, concentration, orientation, and inspection behavior. In general, the experimental procedure that has been used employs questioning and test-like events which sample the knowledges that subjects acquire by reading. The attempt is made to find out how the quantity and variety of acquired knowledge is influenced by manipulations of the frequency, timing, and character of these tests in relation to the printed material. It has been found that these questioning and test-like procedures support the persistence of the kind of behavior that results in learning from reading. Factors contributing to the deterioration of activities which permit subjects to learn from reading text material are to some extent counteracted by the appropriate use of test-like events to which the student must respond in the course of reading. A salient fact is that the character of the questions in the test determines what knowledges are acquired and determines how students inspect, process, and think about the material. Students tend to process, organize, and remember material to meet the criteria posed by the test questions: hence, the nature of these test-like events in verbal material seems to go hand in hand with the kind of attention and complexity of the thought generated in the student.

Punishment

While few are likely to approach this topic in neutral terms, the effects of punishment upon learning can be studied with some degree of scientific neutrality. Work in this area has been carried out primarily with animals, but some work has been done with humans (Thorndike, 1932a, 1932b; Muenzinger, 1934; Estes, 1944; Weiner, 1962; Azrin and Holz, 1966; Fowler and Wischner, 1968). For scientific study, punishment has been defined operationally as the presentation of an aversive stimulus following a response--an aversive stimulus being defined as a stimulus that increases the probability of responses that terminate that stimulus. Punishment has also been defined in terms of its effects, i.e., the reduction of the future probability of a response as the result of the immediately consequent occurrence of a stimulus following the response. This definition is similar to the definition of a reinforcing stimulus, that is, as a consequent event that results in a change in the future probability of behavior. Aversive stimuli that have punishing effects are: (a) stimuli with primary aversive properties like direct assault and electric shock; (b) conditioned aversive stimuli, such as a frown or a shout--generally, a stimulus that has been associated with punishment; (c) time out from or the discontinuation of positive reinforcement when a high level of reinforcement has been in effect; and (d) response cost such as the subtraction of points or the loss of money as a consequence of a response. Punishment results in the reduction and suppression of behavior; these occur immediately if the punishment is effective. The extent and duration is a function of the intensity of the punishment; intense punishment produces rather complete suppression, and mild punishment is followed by a characteristic recovery from punishment. This recovery is often accompanied by an increase in the behavior following the termination of the aversive stimulus. This has been labeled as a punishment contrast effect or designated as a making-up for the decrease of behavior produced by punishment. When punishment is administered on a continuous schedule after every response, the following recovery is immediate; punishment that is intermittently delivered is followed by gradual recovery. As is characteristic of behavior, the suppression of behavior generalizes so that following punishment, stimuli present during the period when reduction of behavior occurs may tend to elicit suppression for a period of time (Azrin and Holz, 1966).

While the suppressive effects of punishment have been the ones most commonly discussed, experiments have shown that punishment has nonsuppressive effects in that it can serve as a discriminative stimulus or cue to signal another event. It may signal another punishing stimulus, the absence of reinforcement, or the presence of reinforcement. In the latter case, it may be a signal that a correct response has been made which will lead to reinforcement (Fowler and Wischner, 1968). The nonsuppressive effects of punishment generally refer to the fact that mild punishment for a correct response facilitates the learning of a discrimination by making the particular stimulus situation highly distinctive; this has been shown in animals with electric shock during discrimination learning. The general conclusion to be drawn is that the procedure and conditions of use of an aversive stimulus determine what effects it can have--either suppressive, or facilitative as a distinctive cue. As a facilitator, the punishing shock can provide information about which responses will lead to reinforcement, and the fact that punishment signals a reinforcement deemphasizes its suppressive effects. Punishment also facilitates learning when an alternative response is available which will not be punished but will produce the same or greater reinforcement as the punished response. For example, punishment of criminal behavior can be expected to be more effective if noncriminal behavior is available which will result in the same advantages as the criminal behavior.

While punishment has not been extensively studied, so that little is known about it, the general statement is that an aversive stimulus is indeed a stimulus and functions as such. Depending upon the conditions under which the aversive stimulus occurs, the different functions it serves can predominate: it can have rather dramatic effects in suppressing behavior; at the same time, it seems helpful in the learning process when used as a discriminative or information-carrying cue, and when it is combined with reward for some other behavior which produces the same or greater reinforcement as the punished response. While an aversive stimulus can act as a discriminative stimulus in facilitating learning, the elimination of a response by punishment does not, as such, result in an increase of unpunished more desirable responses unless these responses are concurrently being reinforced. When a subject is forced to choose between two responses, however, there may be an increase in the unpunished response without any obvious reinforcement for that response. Thus, it is inappropriate to consider punishment as a method for teaching new behavior, punishment is rather a method for suppressing behavior, and in this sense is an antithetical process to reinforcement.

Other procedures are also effective in suppressing behavior, such as extinction, satiation, and removal of a discriminative stimulus. Extinction could be a more effective procedure than punishment; however, under certain situations, it may be difficult to withhold reinforcement. Running or speeding in a car allows us to get where we are going quickly, and hence, running and speeding are inevitably reinforced in a situation where extinction, i.e., the withholding of reinforcement, may not be feasible (Azrin and Holz, 1966). In such situations, punishment probably serves to suppress behavior since it comes about "naturally" when the runner falls or the speeder has an accident. On the other hand, it is possible to eliminate punishment as an institutional procedure--procedures such as fines, imprisonment, dismissal from a job, withdrawal of privileges, etc. A frequent reason for wanting to eliminate punishment is that it produces disruptive and undesirable emotional states. This depends upon the conditions involved. The punishments which come about in the physical world, like a child being burned by touching a hot stove, lower the likelihood of the child touching the stove again, but do not necessarily result in chronic emotional stress. It is when punishment is administered by one individual to another that the undesirable effects of punishment are particularly manifested (Azrin and Holz, 1966). When a teacher punishes a child for talking in class, the teacher desires to suppress the unauthorized talking and not influence other behavior. However, when alternative behaviors are available, punishment tends to allow other behaviors, like escaping from the situation, to be reinforced. In this case, punishment would result not only in the suppression of talking but also in an increase in likelihood of the child leaving the punishing situation through tardiness, truancy, and dropping out of school. The social aspects of punsihment are especially undesirable. When physical punishment is administered, the punished individual may eliminate the punishing contingency by aggressing against who or what is delivering the punishment in the effort to remove it. A related kind of aggression that has been intensively studied in animals occurs when a painful stimulus is delivered to an organism in the company of other organisms (Ulrich and Azrin, 1962). Even though the other organisms did not deliver the painful stimulus, there is a reflexive fighting and social aggression that appears to be a general response to the aversive stimulation.

Part II: Categories of Behavior

As has been indicated earlier, the ways in which the foregoing processes influence learning are a function of the kind of behavior being learned. Depending upon the kind of performance to be taught and the existing behavior of the learner, the various processes of learning come into play. Different classes of behavior require different conditions for learning. Major categories of behavior that have been and are being studied experimentally are: rote verbal learning, psycholinguistics, memory, concept learning, problem solving and thinking, and perceptual and motor skill learning.

Rote Verbal Learning

Three tasks, serial learning, paired-associate learning, and free recall have been most frequently used in rote verbal learning studies. Characteristic of this area of study is the fact that these tasks have been analyzed in detail and the explanatory theories generated are highly specific to the kind of task involved. For example, the most documented and thoroughly studied characteristic of serial list learning is the serial position effect. This effect refers to the distribution of errors during learning, errors being most frequent in the middle of the list and progressively less frequent towards the end of the list, with the peak of the error distribution displaced toward the end of the list. Attempts to explain this have a long history (Lepley, 1934; McGeoch and Irion, 1952; Hull and others, 1940; McCrary and Hunter, 1953; Deese and Kresse, 1952; Glanzer and Peters, 1962). In psychology in general, the way in which the subject perceives the stimulus has been of continued interest (Lawrence, 1963). This question has been a particular focus in the study of verbal, learning where the distinction between the nominal and the functional stimulus, i.e., the stimulus as conceived by the experimenter and perceived by the learner, has been of interest (Underwood, 1963). In serial learning, the serial list can be conceived of as a set of stimulus-response associations where each item in the list functions as both stimulus and response, so that the list of items, a, b, c, d, consists of lines a - b, b - c, c - d, which are eventually integrated into the chain. The view held in this kind of analysis is labeled the "specificity" hypothesis; the stimulus for a given response is the specific prior item and no distinction is made between the nominal and the functional stimulus. Alternately, however, the "ordinal position" hypothesis states that the functional stimulus is the item's ordinal position in the list, so that the functional stimulus for item c in the above list would be the learner's discrimination of c as the third item in the list (Ebenholz, 1963; Young and others, 1963). A "cluster" hypothesis has also been advanced which suggests that the functional stimulus is not simply the preceding item, but some group of items preceding the item to be anticipated (Horowitz and Izawa, 1963). The answer to the question of the functional stimulus, if indeed it is the correct question, is an open one (Jensen, 1962).

A two-stage analysis of acquisition in paired-associate learning dominates contemporary research on this task (Underwood and Schulz, 1960). The first stage is response learning, which consists of making the response available to the learner. For example, the difficulty of learning a verbal unit is related to its meaningfulness or familiarity; a response term which is a nonsense syllable requires more time to learn to recall than a familiar word. The second stage is the association stage in which responses are "hooked up with," or come under the control of, the appropriate stimuli so that each stimulus elicits an appropriate response. Much of the research in verbal learning is oriented toward the processes and variables that influence one or both of these stages of acquisition.

Conditions of presentation. Paired-associate tasks are generally presented by the "anticipation method" where the subject anticipates the response coming up next when the stimulus is presented, or by the "recall method" in which a block of paired words are presented at one time followed by a test trial in which just the stimulus terms are presented. The anticipation method permits immediate feedback of response correctness. The recall method separates learning and test trials and delays any overt information feedback during the test trial until the following study trial. Comparisons of the relative efficiencies of these two methods do not show consistent advantages for one procedure over the other (Battig and Brackett, 1961; Battig and others, 1963).

Studies of confirmation versus prompting procedures have been carried out. In the anticipation method a subject receives immediate confirmation of the correctness of his response, and early in learning he makes frequent errors. It is possible to prevent errors from occurring by prompting the subject as to what the correct response is on a trial. When confirmation and prompting are compared, the results obtained in different experiments are inconsistent (Cook and Spitzer, 1960; Hawker, 1964). Studies have also compared fixed versus random ordering of paired associate lists and have continued to investigate the relative effectiveness of whole versus part learning (Kausler, 1966). In general, the above kind of comparison studies of presentation conditions have been non-definitive, and the variables that have been studied do not seem to represent particularly influential variables in the acquisition of rote verbal learning.

Temporal factors. The amount of time that verbal materials are presented to the learner is an effective variable. Experiments show that not only is the amount of time per item (intra-trial rate) important, but also the distribution of time between practice and rest, i.e., distributed practice. With respect to intra-trial rate, a significant generalization seems to be that presentation time multiplied by trials, i.e., the total time taken to reach criterion, is a constant. Total time in practice may be divided into many brief repetitions of the material or concentrated in a few repetitions with a longer time allowed for each repetition; either procedure with the total time constant appears to result in equal learning (Bugelski, 1962; Nodine, 1965; Keppel and Rehula, 1965).

With respect to the distribution of practice, a long-term systematic attack on the problem (Underwood, 1961a) complicates the earlier general conclusion that short periods of rest are beneficial to learning. The complicating factor is the nature of the task as a source of potential interference between items during the response stage of learning. If responses are highly similar to one another, e.g., nonsense syllables made up of only a few letters, distributed practice will improve performance (Keppel, 1964); but, in general, the greater the degree of meaningful internal organization within the material to be learned, the less the influence of distribution of practice (Deese and Hulse, 1967).

Instruction to learn--incidental and intentional learning. Incidental learning has a long research history in which differences between intentional and incidental learning have been explained in terms of the ambiguous concept of "set," or readiness to learn. Contemporary interpretations (Postman, 1964) view intent instructions as a stimulus for cue-producing responses which influence acquisition. These responses are a kind of orienting behavior which enables the subject to perceive or to discriminate certain features of the stimulus material. Instructions are effective to the extent that they elicit the cue-producing or orienting behavior necessary for a stimulus to be discriminated and related to a response. Incidental learning occurs to the degree that such orienting behavior is elicited by instructions or by the properties of the task materials involved (Rothkopf, 1965). The present literature leads to the conclusion that there is little reason to maintain a conceptual distinction between intentional and incidental learning. There is little experimental evidence demonstrating incidental learning in the traditional sense of a learning process which occurs when there is no motivation, self instruction, or set to learn. What seems more relevant is to treat experimental instructions as a manipulable experimental variable and to investigate the properties of certain materials to elicit orienting responses (Postman, 1964).

Meaningfulness and familiarity. The meaningfulness of rote material is positively related to its acquisition. It is generally assumed that differences in meaningfulness reflect variations in the frequency of prior experience--the greater the degree of prior experience, the higher the meaningfulness. As a result of this prior learning, highly meaningful response units are emitted earlier in practice than are less meaningful components, and, hence, the more meaningful units are more readily available for the associative stage of acquisition (Underwood and Schulz, 1960). In this associative stage, the meaningfulness of both stimulus and response components is hypothesized to be an important factor because meaningfulness determines the number of associates that are accessible for mediational processes. "Familiarity" acts similarly to "meaningfulness," but an operational distinction is made between these two terms: familiarity is the consequence of frequency alone, whereas meaningfulness is the product of both frequency and multiple associations (Noble, 1963). A related variable is pronounceability: experiments show that the pronounceability of the response unit is a good predictor of paired-associate response learning (Underwood and Schulz, 1960; Martin and Schulz, 1963). There is little doubt that "meaningfulness" is an important variable influencing learning; the task of contemporary research is to analyze why this is so and to identify the process involved.

Similarity. Similarity can be "formal," i.e., similarity in terms of the commonality of the letter components of the verbal units, and also "semantic," i.e., similarity in terms of commonality of meaning. In general, similarity of either kind among the stimulus and response components in rote verbal learning tends to result in generalization gradients which produce intrusion errors that slow down acquisition. Study of the effects of similarity shows a long history of skillful experimentation to tease out empirical findings and to analyze theoretical explanations (Underwood, 1961b), but inconsistencies with respect to this variable abound.

Organizational factors. In the free recall task, because of its relatively unstructured nature, organizational processes have been more amenable to study than in more structured tasks (Tulving, 1962). Two representative and related processes are "coding" and "clustering." Coding, as previously described, refers to the observation that people have a fixed memory capacity and appear to regroup or organize a stimulus sequence into manageable units. An encoding process is involved by which verbal strings are grouped, and learned and remembered in terms of these groupings or "chunks" of information (Miller, 1956). For example, in learning a trigram like GDO, the separate letter units may be coded into the meaningful words GOD or DOG--the encoded stimulus, being a meaningful word, now exists as a single unit, rather than separate letters, and is easily acquired and stored for recall. In order to remember a sentence, we may need only to remember a few key words and its general structure. Mnemonic devices provide other means for introducing organization into material and serve to increase the number of words per chunk. Many facts about the learning and recall of verbal material fit into this view, and the particular ways in which the coding process operates is an important subject for study (Underwood and Keppel, 1962).

Clustering refers to the sequential organization during recall of items that are related to one another in some way, even though the items are exposed in a random order during study trials. Clustering is observed when related items follow one another when the subject recalls them. This grouping permits a list of n words to be encoded into fewer than n chunks. In general, acquisition measured in terms of the recall of items in a list is higher for those which do not. Clustering occurs in different ways. Taxonomic clustering occurs when a list contains items that are representative of distinguishable categories, e.g., animal, vegetable, and mineral. In this case, clustering is evident when the learner tends to recall items in groups according to such categories (Bousfield, 1953; Bousfield and others, 1958). Associative clustering occurs when a list contains words in which one word is a common response to another, e.g., chair as a response to table. In this case, clustering occurs as a function of the associative strength between the words (Cofer, 1965).

The influence of contextual organization on the basis of learned syntactic and semantic rules is being increasingly recognized in the study of organizational factors in rote verbal learning. Contextual organization, as an independent variable, has been studied in free recall and in the serial acquisition of strings of verbal material. Increasing approximations to continuous English text results in greater recall as the material approaches English. Recall increases rapidly through the low orders of approximation to English with little change once a certain level of approximation is reached (Miller and Selfridge, 1950; Deese, 1961). Syntactic constraints by themselves have been studied by retaining essentially the grammatical features of ordinary English, substituting nonsense material for nouns, verbs, etc. The syntactically structured strings are learned more rapidly than unstructured, even when both strings are semantically meaningless (Epstein, 1962). Both syntactic and semantic aspects of verbal material also facilitate their acquisition. Normal sentences, retaining either syntactic or semantic form, give higher recall scores than random word strings (Marks and Miller, 1964). As meaning and structure is introduced into verbal materials, many new variables interject themselves for study (Miller, 196; Mandler, 1962).

Mediated association. Mediation, defined as association learning between events where their contiguity is not evident, occurs through the common elements of organizational structuring as have been described above, clustering, contextual organization, etc. In the context of rote verbal learning, the principle of mediation asserts that associations sometimes come about between two elements a and b because they are both associated with a third element c. The third term serves to bridge the gap between two noncontiguous terms. Much effort has been made to analyze this hypothesized process and to describe the apparently noncontiguous associations which humans learn. Mediation behavior has been defined in a variety of experimental paradigms, and its occurrence or nonoccurrence under various conditions has been the subject of experimentation and theoretical explanation (Osgood, 1952; Jenkins, 1963). Verbal mediation also facilitates learning of non-verbal events; for example, it has been shown that words encode a visual display, so that the greater the difficulty in describing the pattern (or the greater number of words needed to describe it) the less accurately it can be reproduced (Glanzer and Clark, 1963). Mediation, while generally thought of as a covert process, also appears to be a behavior which can be elicited, reinforced and learned as readily as overt behaviors. Mediation is best thought of, not as an automatic, unlearned process but as a behavioral act which depends upon the previous behavior of the learner and the conditions present in the immediate learning situation (Jenkins, 1963). In general, the behavior involved in mediation occurs through a chain of associative links, or as a function of organizing concepts and rules which permit a variety of stimuli to be associated with a common concept or principle which enables a particular response to be generated (Deese and Hulse, 1967).

In recent years, the study of rote verbal learning tasks has undergone some changes in perspective. (1) A first point is that in the past, traditional association theory and the related laboratory techniques have been based upon two primary assumptions: (a) that a major element of learning is the paired contingency obviously apparent in list learning and, (b) that it is necessary to keep at a minimum the possible influence of pre-existing, pre-instructional behavior. These two assumptions have dictated the emphasis on paired-associate and list learning tasks and on theory concerned with behavior in the learning of simple word pairs. Experimental evidence has shown that the behavior of the subject is less under control of the experimental conditions than the experimenter has imagined. As a result, organizational factors or modes of response which result from the entering behavior of the subject and from the properties of a particular task have gained prominence as experimental variables. (2) A second point is that the associative laws in rote verbal learning are being restated in terms of the fundamental processes observed in other areas of human and infrahuman learning described earlier in this review. For example, data on the structure of associations among words are interpreted in terms of elements that are related because they are contrasted in some way (discrimination), and elements which can be grouped because of common characteristics (generalization or acquired similarity) (Deese, 1965). The persistent and tightly planned research on contiguous paired learning may have obscurred the relationship of rote verbal learning to other categories of behavior and restricted the behavioral processes involved so that it has been difficult to devise experimental situations to bring them under appropriate control. During the last decade, the area of verbal learning has grown at a very rapid rate and much is changing in the field (Keppel, 1968).

Psycholinguistics

When human beings use language, they continuously produce utterances which may be quite new to the speaker or the listener but which, at the same time, are recognized by both as conforming to some rules which permit communication. The structural rules or grammar of language is a major characteristic and property of the language task, but until recently little psychological work has been concerned with it. Two reasons for this neglect are (a) the nature of the tasks generally used in the study of verbal learning and (b) the lack of adequate task analyses of language performance. At the present time, psychologists are involved in active study of the grammatical aspects of language, capitalizing on the systematic analyses provided by developments in linguistics (Lees, 1957; Ervin-Tripp and Slobin, 1966). The linguist has classified primarily two aspects of language: (a) the rules, structures, and transformations that make up or comprise the syntax of the language, and (b) the classes of units or parts of speech that the syntax orders. Within this context the psychologist is concerned with such questions as: how is the syntactic structure learned and developed; what psychological processes influence these changes; what determines the use of particular syntactic forms under various conditions of performance in the adult;

how does the speaker generate and how does the listener assign parts of speech to appropriate categories.

For a number of years, psychologists working in this area have taken as their language model a finite-state grammar. As sentences proceed from left to right on the printed page, the reasonable assumption is that each succeeding word should be probabilistically dependent on the preceding words. A Markov-type generating procedure seems useful for this model since the probabilities at each transition point depend upon previous experience and learning, this experience providing both lexicon and rules of grammar involved in this transition (Osgood, 1963). More recently, it has been argued that such a finite-state generator could not produce the potentially infinite set of grammatical structures, including the novel ones that characterize any natural language (Chomsky, 1957). The Markov model also does not seem to be able to handle the deep imbedding of qualifying clauses that characterize sentences in natural languages. To account for these difficulties, a phrase structure grammar is employed which permits a sentence to be resolved into immediate constituents such as a noun phrase plus a verb phrase which are further broken down into their immediate constituents which again may be further broken down. At each level "rewrite rules" prescribe the operation of going from one level of analysis to the next. When the structure of the sentence is laid out, words from a stored vocabulary (dictionary or lexicon) can be assigned to the elements of the sentence. This procedure defines a generative grammar in which certain rules of transformation are applied to basic or kernel sentences and these sentences are rewritten according to these rules until the desired sentence is derived (Miller, 1962). Implicit in this analysis of grammatical structure provided by linguists is the assumption that the speaker of the language generates the grammatical structure of speech by applying these transformational rules. The rules specify the structure of basic word strings or kernels, the ways in which these kernels may be transformed into new structures, and the ways the resulting structures incorporate a lexicon and are actualized in the spoken word. The model is presented and it is assumed that this is related to the way individuals behave; it is this assumption about the behavior of individuals that provides a challenge to psychologists (Carroll, 1964). Whether or not this model is useful as a theory of behavior, a central problem in psycholinguistics is to account for how humans learn the kind of language competence described by linguists.

The impressive work of the linguists in analyzing language performance has had a significant influence on the study of verbal behavior. Syntactic categories, largely ignored in the traditional work in verbal learning, now appear as components of stimulus and response. The syntactic dimensions of word associations are being investigated (Deese, 1965). In paired-associate learning, the influence of syntactic categories has been shown by studying the different effects of content and function words (Glanzer, 1962). Systematic changes in word association have been shown to be correlated with increases in the ability to handle new words grammatically (Brown and Berko, 1960; Berko and Brown, 1960). The learning of syntactic and grammatical categories is being carefully investigated in young children. Theoretical learning models have been suggested for the process by which a child builds up the grammatical classes necessary for speech (Jenkins and Palermo, 1964). A generative grammar has been constructed on the basis of samples of the utterances of young children (Brown and Fraser, 1963). The learning of the grammatical order of words has been described in terms of "contextual generalization" which comes about when a child learns the position of a unit in a word sequence (Braine, 1963). These units are phrases within sentences, sequences of phrases, and morphemes within phrases. The learning of locations involves the process of learning the sounds of units in the temporal positions in which they recur. Thus the child learns, one at a time, that each of a small number of words belongs in a particular position in an utterance; he learns to say "that doggy" but would never say or literally respond to "doggy that." He learns, in the earliest phase of speech, that certain words act as pivots which occur in an initial position or in a final position, and that these pivotal words are either preceded or followed by many of the words in his vocabulary. During this first phase, language grows structurally by the formation of new pivot words and by learning the position of new words; the language grows in vocabulary as words are placed around these pivots, and in a sense, elementary syntax and a lexicon are built up. Linguists have made direct applications to the teaching of reading and spelling involving the detailed analysis of the relationship between the sounds of English and the orthography used to represent sounds (Fries, 1963).

Linguistic analysis has had a strong influence in restructuring the work in verbal learning; however, much work still centers around the laboratory rote verbal learning tasks such as paired-associate and serial learning previously described. While this work is of much scientific interest in verbal learning, it seems quite remote from language tasks in the classroom, since practically all the work has concerned itself with the learning of relationships between words and between nonsense syllables without regard to the influence of grammatical classes or the role of words in linguistic structures (Carroll, 1964a). While recent trends have emphasized syntactic behavior, "meaning" continues to be a problem needing a satisfactory method of experimental attack (Ervin-Tripp and Slobin, 1966). In this area, the work of psychologists has included the following: (a) associative meaning, involving various measures of similarity of meaning based on the overlap between associations to words (Marshall and Cofer, 1963; Underwood and Schulz, 1960; Deese, 1965); (b) The semantic differential, which appears to be a measure of metaphorical or affective connotation as distinguished from a measure of denotation (Osgood and others, 1957; Carroll, 1959); and (c) semantic generalization of conditioning indices which involve the generalization of conditioned autonomic responses, e.g., galvanic skin response and heart rate, as measures of meaning similarity (Feather, 1965; Razran, 1961). Attempts have been made to consider linguistic notions in the area of semantics (Katz and Fodor, 1963). Further, the results obtained in many areas of learning through the manipulation of reinforcement variables is impressive enough so that such variables need to be included in studies of the learning of language. The literature on reinforcement variables in verbal behavior is sparse but studies are increasing (Holz and Azrin, 1966; Dulany, 1961). Another area in which an active trend seems to be continuing is the effect of language behavior on learning, involving such aspects as the effect of verbal instructions and labeling, and the postulated effects of internal verbal mediation (or covert language control) on cognitive behavior and self-direction (Ervin-Tripp and Slobin, 1966).

Memory

Operationally speaking, remembering and forgetting refer to what takes place in the interval between the occurrence of learning and subsequent use of the learned behavior. The behavior referred to as "remembering" consists of such behaviors as reconstructing memories of the past or recalling some performance learned in the past, e.g., riding a bicycle, recognizing something that is familiar, or relearning a performance that has been to some extent forgotten. Traditional explanations of forgetting have included the following: (1) passive decay through disuse, as in Thorndike's Law of Disuse (Thorndike, 1913); (2) systematic distortion of memory, in which there are qualitative changes in what is remembered, such as have been shown in experiments on testimony; (3) interference effects, which suggest that forgetting is not so much passive decay over time, but rather is determined by new learning or previous learning that interferes with memory; and (4) motivated forgetting as exemplified by the principles of repression whereby memories become inaccessible because they relate to personal problems or by the Zeigarnik effect which hypothesizes that unfinished tasks are remembered more readily than finished tasks. In recent years, memory has been the center of increasing interdisciplinary interest, with studies being carried out in biochemistry, neurophysiology, and psychology. Within psychology, new experiments have changed the emphasis of what are significant variables for study, and there has been an increase in a strong theoretical interest to explain the nature of the memory process (Melton, 1963; Adams, 1967; Keppel, 1968).

Work on the memory process has centered around three main issues: One is the dependence of memory retrieval on the reinstatement or similarity of stimulus conditions from trial to trial, the general principle being that remembering is a decreasing function of the amount of stimulus change from one trial to another (something like generalization decrement). Failure of memory in this case is a function of stimulus change. A second issue is the interaction of memory elements or traces. This is the focus of the interference theory of forgetting which hypothesizes that memory retrieval is a function of the interactions between prior learning and new learning. From this point of view, failure of memory is the result of interference. When new learning interferes with old, the phenomenon is called retroactive inhibition. When prior learning interferes with the learning of new material, it is called proactive inhibition. A third issue is the relationship between repetition and memory. In recent developments, this issue has been reanalyzed into the examination of whether there is a fundamental discontinuity between memory established by a single repetition (short-term memory) and memory established by multiple repetitions or single repetitions with the opportunity for consolidation (long-term memory).

A significant development in interference theory has been the emphasis that a major mechanism influencing memory is long-term proactive inhibition as a result of prior language habits (Underwood, 1957; Underwood and Postman, 1960; Postman, 1961). A reanalysis of early experiments in combination with new experiments suggests that the potentially greater importance of proactive inhibition (interference generated by previous learning) than retroactive inhibition (interference generated by new learning), and that proactive inhibition may be attributable to interference coming from outside the laboratory situation. This extraexperimental interference is more likely to be proactive than retroactive because the opportunity for acquiring competing verbal habits is greater prior to the experiment than during the relatively short time intervals used in laboratory investigations of retention. While losses in retention can result from interference by verbal behavior that occurs before or after a particular learning session, the new emphasis on proactive inhibition attributes forgetting primarily to interference from stable language habits with which the learner enters the learning situation. These notions have some important implications for the future direction of research on forgetting. Psychologists studying verbal learning are spending less time devising materials which strip away the influence of previously established verbal habits, as was Ebbinghaus' intention when he invented the nonsense syllable and as has been the intention of much of rote verbal learning research. The strategy of the new type of studies, it has been suggested, will require the assessment of the status of existing language habits in the subject prior to new learning, the definition of new learning tasks with explicit recognition of elements of the new task in relation to preexisting ones, and the measurement not only of the retention of new learning but of the recovery and memory of old learning which may interfere with it (Melton, 1961).

In recent years, duplex theories of memory have been proposed (Atkinson and Shiffrin, 1968; Broadbent, 1963; Waugh and Norman, 1965) which essentially postulate two components of the memory system: a short-term memory store and a long-term memory store. The short-term store (STS) may be regarded as an individual's "working memory." The STS has a limited capacity, and information in it decays relatively rapidly over time; information in it can also be displaced by new incoming information. The long-term store (LTS) differs from the STS in that information stored in it is relatively permanent and does not decay and become lost. The LTS has a relatively unlimited capacity although it may be modified or rendered temporarily irretrievable as a result of distortion or interference from incoming information. The LTS seems to involve the kind of decay and interference characteristics that have been investigated in the classical studies of memory. In the STS, in the LTS, and in the transfer between the two, it is postulated that the individual uses certain "control processes" to handle the memory task. These control processes involve storage, search, and retrieval strategies, and their particular mode of employment depends upon such factors as instructional set, the experimental task, and the past history of the subject. The main control mechanism for increasing storage in STS is a rehearsal process. Since the number of items of information that can be rehearsed is limited by the capacity of STS, information in STS in excess of the rehearsal capability decays at a rapid rate, and search must be performed efficiently. Transfer from short-term to long-term memory store involves coding processes. The information temporarily stored in STS is translated into "chunks" of information that can be readily stored in LTS. Coding processes involve the selective alteration of information so that it is more easily and more compactly stored by the individual. These coding changes can take a number of forms such as the use of mnemonics, mediating categories, and organizational structures. The individual may organize information by grouping items of information into sets and memorizing the set as a whole rather than as the individual items, or he may break the information into chunks of a desired magnitude that facilitate remembering. Once information is transferred to the LTS, it is available for retrieval for subsequent remembering. In order to carry out a retrieval process, the individual can search the information according to certain organizational patterns, i.e., geographically, alphabetically, or temporally. It also seems reasonable to conjecture that cues or labels with which the individual enters LTS can determine the success or failure of the retrieval process. In contrast to these control processes which the individual implements, the processes of decay and interference are features which pertain to the underlying operation of memory. Within LTS, the work on interference theory would indicate that the effects of proactive and retroactive inhibition would cause confusion and competition between components that are similar and make search and retrieval difficult. At the present time, there are many experiments underway to investigate the speculations of duplex theories of forgetting, and particular features of the theories are being rejected and confirmed by experimental evidence (Atkinson and Shiffrin, 1968; Keppel, 1968).

Concept Learning

The learning of concepts has been of sustained interest to psychologists and educators (Hull, 1920; Bruner and others, 1956; Bourne, 1966; Brownell and Hendrickson, 1950; Carroll, 1964b; Glaser, 1968). In general terms, concepts inject both a uniformity and adaptability into behavior; as concepts are learned, they establish what particular experiences have in common with other events and also indicate the extent to which they differ from each other. Concepts are learned by experience with appropriate and inappropriate instances or exemplars of a class; properties of these exemplars are abstracted and become the stimuli according to which an instance is classified as a member or a nonmember of a concept class. The formation of a concept and the process of abstraction are probably never complete; while simple concepts may become reasonably stable, subtle and complex ones constantly undergo emendation and revision as new instances occur. Operationally speaking, conceptual behavior involves the making of a common response to different stimuli; in contrast, in a paired-associate task, a different response is learned for each stimulus. In a concept task, the individual responds in one way to a *set* of stimuli and in another way to another *set*. In this sense, events are categorized by discriminating between instances and noninstances of a category or class and, within a category, behavior is generalized so that a new instance with relevant properties is included in the concept class. When potential class instances are presented to the learner, they involve a number of attributes according to which they might be categorized. Some of these attributes are relevant to the concept being formed, and others are irrelevant to it. The concept learning task usually involves the necessity for discriminating between irrelevant attributes and those attributes or combination of attributes which define the concept class.

In general, then, concept learning involves generalizing within classes and discriminating between classes. For example, given three sets of geometric figures, e.g., triangles, quadrilaterals, and circles, the student learns these three concepts when he generalizes among the various kinds of triangles and categorizes them correctly as "triangles," and when he discriminates between the three classes of figures and labels them as belonging to different categories. Knowledge of whether concept learning has taken place is obtained when the learner makes these appropriate category responses and is able to apply the "classification rule" (verbalizable or not) to a new set of instances involving the concept attributes. The kind of rule by which attributes are combined to form a particular concept determines, to a large extent, the complexity and nature of the concept. When a rule is not too complex, it is possible that a student can memorize the instances that belong to that category without learning the rule; such a possibility leads to the concern in school learning about whether the student has "just memorized" or "really learned" the concept.

In studies of concept learning (Bourne, 1966; Kendler, 1961; Kendler, 1964) many different variables have been investigated: the effect of learning from positive and negative concept instances (Bruner and others, 1956; Hovland and Weiss, 1953); the number of relevant and irrelevant attributes involved (Shepard and others, 1961); the redundancy of concept instances (Bourne and Haygood, 1961); the order and sequence in which concept instances are presented to the learner (Hovland and Weiss, 1953; Detambel and Stolurow, 1956); the perceptual salience and dominance of concept attributes (Heidbreder, 1946a; 1946b; Grant and others, 1949; Wohlwill, 1957); the effects of prior verbal associations (Underwood and Richardson, 1956); reinforcement schedules (Green, 1955); and the amount and nature of information feedback (Buss and Buss, 1956;

Suppes, 1965; Azuma and Cronbach, 1966). A prominent experimental finding is that individuals do not learn efficiently from negative instances even when the informational content of these instances is equated to that of positive instances. It also appears that the difficulty of concept learning is related to the number of relevant attributes and that the addition of even a single irrelevant attribute adds considerably to the difficulty of the task. Task conditions have been analyzed to some extent in terms of the following: how the objective of the concept learning task is defined; the nature of the instances encountered; the opportunity for feedback and the validation of instances; the consequences of making correct or incorrect categorizations; and the nature of imposed procedural restrictions such as speed requirements and the opportunity for memory and record keeping (Bruner and others, 1956).

With some exceptions, the kind of concept rule that has been studied in the laboratory has been the conjunctive or disjunctive combination of attributes where the defining rule is their joint presence or absence. Recently, different types of concepts have begun to be investigated and other logical operators than conjunction and disjunction are being examined, e.g., exclusion, negation, and certain conditional rules (Haygood and Bourne, 1965). The empirical finding is that logical complexity is a factor contributing to the difficulty in concept learning. However, examination of the experimental literature makes it clear that the work on concept learning has been primarily performed with particular kinds of concept rules, and other types of concepts related to school subject learning need to be examined. Many school-learning concepts deal with relations among dimensions rather than their combined presence or absence; for example, concepts like "many," "few," and "average" require the learner to think in terms of the relationships between a base quantity and a reference quantity. In addition, new concepts learned in school depend upon concept attributes which themselves represent concepts and depend upon a network of prerequisite concepts. This notion of the hierarchical structure of concept learning has been pointed out with respect to the teaching of mathematical concepts to children (Suppes, 1966). Research on the learning of concept hierarchies will undoubtedly emphasize the importance of measuring transfer effects as a way of assessing the effectiveness of instruction.

Other new looks at the study of concept formation are taking place. It has been pointed out (Bourne, 1966) that concept learning problems in which the rule is neither familiar or simple have not been studied very often. Typical concept learning studies have emphasized the identification of relevant attributes, and once the relevant attributes have been identified, the rule involving them is trivial or previously indicated to the learner in some way. Problems wherein the rule needs to be learned or discovered have been examined less often. Also, little research is available on concept learning in different sensory modalities, for example, auditory concept formation, which seems related to the teaching of music, and sensitivity to language tones. Language concepts and the influence of language on concept learning are essential aspects of school learning, and, while in the past, most of the work in the learning laboratory has been on nonverbal concept attributes, like geometric figures, work is increasing on language and language influences. The ability to use words appears to be an important factor in the speed of concept acquisition, and required verbalization may facilitate concept learning in very young children (Dietze, 1955; Jensen, 1966). However, the correlation between verbalization of a rule and correct responding is not clear, and verbalizations are not always a guarantee that categorizing behavior will be appropriate (Green, 1955). In addition, the fact that there is a difference between children and adults in performing solution shifts in concept problems suggests the influence of verbal mediation and of prior verbal habits (Kendler and Kendler, 1962).

Theories of concept learning have been interesting, but have not contributed much to new information or to the search for it. Theoretical descriptions and formalisms in this area have generally been used to flex the muscles of the theories themselves and examine how adequate they are to describe experimental data. Stochastic mathematical models (Bourne and Restle, 1959; Bower and Trabasso, 1964) have handled only the simplest situations; these models, however, have emphasized the issue of incremantal versus one-trial learning, a question which may be significant for classroom learning (Suppes, 1965; Grier and Bronstein, 1966). Information-processing models (Simon and Kotovsky, 1963; Hunt, 1962; Reitman, 1965) are of interest in two ways: (1) providing a description of the characteristics of skillful conceptual performance; and (2) suggesting a methodology of investigation which is sensitive to the individual differences among learners (Gregg, 1967). It would seem that concept learning, standing in a central position between basic and more complex behaviors, should be one of the main points of contact between various theories of behavior, as well as between behavior and its theoretical description. Finally, it is to be pointed out that present knowledge of concept learning has been quite directly applied to the teaching of the discriminations and generalizations required to produce conceptual behavior (Mechner, 1965).

Problem Solving and Thinking

Definition of this category of behavior and specification of the tasks and task environments that are identified as those in which problem solving and thinking take place have not comprised a very systematic endeavor in the psychology of learning. One thinks of the puzzles and problems used in psychological experiments such as the two-string problem, "twenty questions," the water-jar problem, Wertheimer's parallelogram, anagrams, trouble-shooting problems, and reversal shift problems. Upon examination of such tasks, one is impressed with the diversity in the field and with the fact that many of the tasks employed are of a puzzle or game variety which are not especially designed to investigate problem situations relevant to various subject matters (Ray, 1955). It seems reasonable to include both problem solving and thinking in the same category; a recent detailed analysis and attempt at systematizing psychological work in this area employs the term "directed thinking" and defines it as thinking whose function it is to convey solutions to problems (Berlyne, 1965). Less experimental work is available on "autistic thinking" as exemplified by daydreaming or generalized free association.

In the studies that have been performed on problem solving, a major aspect that has been emphasized is that the identity or pattern of the stimuli (objects or events) in the situation changes in the course of problem solving. Objects take on different functions so that a solution can be achieved; as a consequence, stimuli are used or combined in a way that is different from the way in which they are presented or from the way in which they are most familiarly used. The responses of an individual achieving a solution are not tied to a particular physical configuration of the stimulus situation, but rather he imposes a reorganization upon these stimuli or sees in them a particular relationship which is generalizable to a similar class of problems, as is the case, for example, in transposition or oddity problems. Another aspect of problem-solving is that an individual utilizes instructions which influence his behavior. Instructions serve such functions as: "defining the problem," "providing an understanding of the goal," "establishing a set," and "introducing direction;" psychologists have been and are concerned with the analysis and investigation of such variables (Gagné, 1964; Duncan, 1959; Goldiamond, 1966). It has also been postulated that in the course of problem solving and thinking, an individual instructs himself through covert language and defines his strategy in this way (Skinner, 1957). It has been suggested (Gagné, 1965a) that problem solving and thinking take place through the use of rules or principles which are built up from previously learned concepts. A rule specifies a relationship between concepts, and a higher order rule is defined as a relationship between previously learned rules. In problem solving these rules are used to achieve some goal, and what emerges from problem solving is the combination of rules into a higher order principle which the individual learns and generalizes to a variety of problems in a given class of situations. With respect to education, this implies that prerequisite concepts and rules must be taught to the learner in order for him to be successful in a problem-solving task. A successful course of instruction would insure that necessary prior learning is in the student's repertoire because without this prior mastery, he would not have the concepts and rules of a particular subject matter available for use.

The study of higher order cognitive behavior has been the focus of information-processing models of thinking (Reitman, 1965). These models assume that the human organism can be conceptualized as an information-processing system, and they attempt to examine thinking in terms of the processes and strategies by which an individual goes about thinking through a problem. The processes involved are set down precisely in terms of charts of information flow. These flowcharts specifically define a program which attempts to simulate human cognitive activity. The first significant attempt to do this involved a description of a program called the Logic Theorist which described an information-processing system which proved theorems in symbolic logic with which only humans had been able to deal previously (Newell and Simon, 1956;

Newell and Shaw, 1957; Newell and others, 1958). The Logic Theorist did not try to solve problems by the brute force technique of searching through all possible sequences of logical operations until one was found to yield a proof; rather, the approach taken was to incorporate methods and rules of thumb (heuristics) of the type used by humans. Human thinking appears to involve such heuristic procedures as: analyzing a problem to which the solution is already known in an effort to guide thinking in a present problem; working backwards in trying to solve a problem; or means-end procedures whereby a current state of affairs is compared with a solution to be obtained and the attempt is made to find an operation which reduces the difference between the two states (Polya, 1954, 1957). In chess playing, a heuristic might be such a rule as "try to control the center of the board." The Logic Theorist made the assumption that programs could be written to solve problems as people do, and was designed to solve a particular problem. A more significant approach was the development of the General Problem Solver (GPS) (Newell and others, 1960; Simon and Newell, 1964). GPS represents an attempt to synthesize in a composite program a set of concepts and strategies assumed to underlie human problem solving quite generally, quite apart from the features that characterize activity in any particular subject area.

Different kinds of programs for concept learning, musical composition, and verbal learning have been presented (Reitman, 19[illegible]), and an interesting comparison has been made between the process incorporated in a computer program designed to solve algebra word problems and the behavior of high school and college students (Paige and Simon, 1966). The general method employed in this work is to simulate in detail the problem-solving behavior of human subjects. Data are obtained by asking humans to solve problems, "thinking aloud" as much as possible while they work. The General Problem Solver was constructed to describe as closely as possible the behavior of the subjects as revealed by their oral comments and in the steps they write down in working problems. The aim of this research is to understand the information processes that underlie human intellectual and adaptive ability and to construct computer programs that can solve problems requiring such intelligence and adaptation. Varieties of such programs are then matched to the data obtained on human problem solving. This procedure results in very complex and involved descriptions of performance, and there is discussion about the relationship between the kinds of behavior descriptions which result and the more usual methods for developing and verifying formal psychological theories.

Perceptual-Motor Skill Learning

Interest in this area by psychologists has fluctuated over the years and at present seems to be increasing because of man's interaction with complicated machines and because developments outside of psychology in communication models, control system models, and adaptive systems seem relevant to the construction of explanatory models for perceptual-motor skill. Examples of this kind of behavior abound: behavior involving gross bodily activity such as walking, jumping, swimming and balancing, and others involving less gross activity such as manipulating tools and objects or controlling machines (writing, typing, playing a musical instrument, sewing, driving a car). In general, these behaviors are characterized by a spatial-temporal patterning, the interplay of receptor-effector-feedback processes, and such characteristics as timing, anticipation, and find adjustment of a response. The phases in skill learning that have generally been identified seem to be the following (Fitts, 1964, 1965): (1) An early cognitive phase in which some sort of "intellectualization" occurs as the student attempts to understand instructions, to analyze the task, and to verbalize what he is learning. At this point in learning, verbal inputs and "talking through" the task appear to be useful. This phase may be similar to the response-learning stage discussed in rote learning where coding or the integration of responses occurs. Also in this phase verbal instructions help shape behavior. (2) An intermediate or "automation" phase which is not unlike the associative stage of rote learning. Stimulus control is established over a response so that responses take place in the presence of specific cues. This stage is characterized by a gradually increasing speed of performance either in terms of time or errors or both. The verbal support which was employed in the early stage of learning appears to drop out or be short-circuited during this second phase, but studies of skill learning in general have not been carried out to examine the detailed nature of this process. A second aspect of this intermediate phase, contributing to apparent increasing "automation," is that as learning continues there is a gradually increasing resistance to stress and to interference from other activities that may be performed concurrently. Neurological evidence suggests that there may be less and less involvement in cortical areas and increasing reliance on proprioceptive feedback and a shift to lower brain centers. Learning during these early and intermediate phases of skill learning might be conceived of as the acquisition of a number of semi-independent sequences (subroutines) which go on successively or concurrently. As learning progresses, these subroutines may be combined, and higher order executive routines may become established; stimulus sampling and reference to external stimuli becomes less frequent; coding becomes more efficient; different aspects of the skill become integrated or coordinated; and strategies and decision processes become adapted to or match the probabilities associated with the occurrence of different stimulus sequences. (3) A late learning phase occurs about which there is relatively little experimental data available. Apparently even in quite simple tasks such as telegraphy, typing, and industrial assembly work, performance continues to improve over millions of cycles of practice. In fact, there appears to be little evidence to contradict the conclusion (Keller, 1958) that a true plateau in skill learning has not been demonstrated and that when such effects are reported they are usually artifacts of measurement. Such very long-term improvements with practice have been shown in industrial tasks and certainly appear to be the case in the development of championship performance in athletics. The leveling off of performance may eventually be due as much to physiological effects and/or loss of motivation, as to the reaching of a true learning asymptote or limit in capacity for further improvement. In this respect skill learning may have a very special characteristic contrasted with other categories of behavior although, in neither case, have studies on long-term learning been frequent enough to say.

An interesting line of research has been correlational analysis of performance at different points in time in the course of skill learning (Fleishman, 1966, 1967). These studies reveal changes in the structure of ability at different stages of practice in the same task. The correlations between the kinds of abilities required in early trials and the abilities required in successively remote trials become progressively lower. For example, a particular ability, say spatial relations, may be relatively important early in practice because the first thing that the task requires is that the subject learn about certain directional aspects of the stimulus in relation to his response. Early in practice some learners may be better at this than others. Later in training, however, spatial relations may become a less significant aspect of the task since all subjects learn this component and it no longer differentiates among them. At this time, other aspects of performance contribute to the task performance and to subject differences in performance competence. In general, the factor structures of complex skills change with practice, indicating that ability requirements are different at different stages of learning. One implication of this is that aptitude tests which employ validation criteria at a particular stage of learning may give an erroneous picture of the prediction of learning success.

Many of the variables that have been studied in other kinds of behavior have been investigated in skill learning (Bilodeau, 1966). Particularly significant as it is in other areas of learning, information feedback in the form of knowledge of results and reinforcing stimuli also provides a significant influence in skill learning. The information feedback cycle in perceptual-motor performance seems especially prominent in the constant receptor-effector-feedback relationship that occurs in a task like driving an automobile or playing tennis. There is increasing recognition that many of the processes involved in other forms of learning such as discrimination, short-term memory, and so forth, operate similarly in skill learning; and the identification of this category of behavior as a unique area for study is disappearing.

The work in skill learning has some special implications for instruction. The importance of continuing practice far beyond the point in time when some arbitrary criterion is reached needs to be emphasized. Individuals who have not had a great deal practice beyond the early and intermediate stages of learning probably do not experience the beneficial increase in resistance to stress, fatigue, and interference that comes from extended overlearning. When the structure of a skill is appropriate, considerable gain may accrue from training on subroutines of a skill where it is difficult to provide "real life" training or the facilities for training on the total skill; subsequent "on-the-job" training can then be carried out on the total task. In a great many skills, subjects may cease to show improvement not because they are incapable of further learning but because some condition of the task environment restricts the opportunity for improvement; most frequently this restriction takes the form of the lack of appropriate performance feedback.

Learning and Instructional Technology

There is abundant evidence that the psychology of learning is entering a stage where it can make increasing contact with techniques of instruction and the study of school learning. When the field of learning was reviewed 25 years ago (Melton, 1941; Estes, 1960) it appeared that impenetrable barriers of research tradition, special interest, and linguistic convention demararcated three principle areas: the laboratory study of animal learning; the laboratory study of human learning, and the study of school learning. It was pointed out a decade ago (Estes, 1960) that the striking development up to that time was the rapidly accelerated and obviously fruitful interchange of concepts and methods between the first two of these three areas. It was becoming possible to express the communalities and differences of the two areas in a common terminology and to interpret them in a common conceptual structure. (In contrast, it seems that today in some quarters, with the emphasis on complex cognitive, verbal-information processes, the methods and concepts of the study of human learning, vis a vis animal learning, are drawing apart.) No such progress, it was said, could be reported toward bridging the gap between laboratory psychology and the study of school learning. The documentation for this was that, with rather few exceptions, reports of research on learning in the classroom carried no reference to the contemporary psychological literature and showed no signs of its influence.

At the present time, however, after another decade has gone by, there is evidence to report that this gap is narrowing. Experimental psychologists are turning their thinking and their enterprises to the analysis and investigation of the educational, instructional process (Skinner, 1958; Bruner, 1960; Holland, 1960: Lumsdaine and Glaser, 1960: Bugelski, 1964; Hilgard, 1964; Suppes, 1964; Gagné, 1965; Gibson, 1965; Gilbert, 1965; Glaser, 1965; Groen and Atkinson, 1965; Moore and Anderson, 1968). It was reported that the NSSE Yearbook on Learning and Instruction published in 1950 (Anderson, 1950) did not list Hull, Skinner, Spence or Tolman in its index. The yearbook on the same topic in 1964 (Hilgard, 1964) lists them all in abundance, and the yearbook itself contains many chapters written by experimental psychologists. The Behavioral Sciences Subpanel of the President's Science Advisory Committee in 1962 specifically called for research in the behavioral sciences relevant to education. Of significance is the fact that research and development have been sponsored by the government to foster the interplay between behavioral science and the educational process. Centers have been established to develop mechanisms and agencies where the process of research, development, and application leading to the design of educational materials and procedures, as described earlier in this review, can be carried out.

There may be emerging an instructional technology based upon an underlying science of learning. Technology in this sense does not necessarily mean hardware and instrumentation, but it does mean technology in the sense of an applied discipline like engineering or medicine. The techniques and procedures which are used by the practitioners of these technological disciplines grow out of the findings in their underlying sciences and also grow by informing science of their needs. Instructional technology is taking a certain shape: (1) The analyses of tasks and task environments, and the behavioral specification of educational objectives and subject-matter competence is becoming an increasingly important endeavor (Lindvall, 1964). The question is being asked about what is being learned so that the study of how it can be learned can be examined with relevance. (2) Individual differences and the behavior with which an individual begins a learning experience is being increasingly taken into account in studies of learning and instruction. This is resulting in interaction between two rather independent traditions of psychology--individual difference measurement and experimental psychology (Cronbach, 1957; Gagné, 1967). (3) The variables influencing the instructional process for tasks relevant to school learning are being examined in many quarters (Gagné, 1965a; Ausubel, 1967; Travers, 1964; Hilgard, 1964; Shulman and Keislar, 1966). (4) Questions are being raised about the appropriate methodology for the measurement and evaluation of the outcomes of learning (Glaser, 1963; Cronbach, 1963). These stirrings have significant implications for the future shape of learning theory and experimentation. Learning theories will take on different requirements. In all probability, in contrast to their present form, they will be more amenable to the social and developmental differences between individuals; they will take on more cognitive, subject-matter-like tasks; and they will pay more attention to the design of experiments that optimize rather than only compare conditions for learning.

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